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Navmar Applied Sciences Corporation
NAVAIR

High Power, InP Lasers for DPSSL – Reliability and Operation Challenges for Harsh Environments

Presentation at OIDA Roadmap Forum: High Power Diode Laser Sources, Palo Alto, CA

May 10, 2006

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **10 MAY 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **High Power, InPLasers for DPSSL -Reliability and Operation Challenges for Harsh Environments**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Princeton Lightwave Inc,2555 US Route 130,Cranbury,NJ,08512**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presentation at OIDA Roadmap Forum: High Power Diode Laser Sources, Palo Alto, CA, 10 May 2006

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**19**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Agenda

- High power lasers – performance and operational requirements for airborne pumping applications
- Summary of current packaging approaches for high power, fibered bars – known and perceived reliability gaps
- Preliminary reliability testing results
- Potential approaches moving forward

Performance Targets

- Fiber coupled for remote location capability
- Low beam divergence
- NA to match output coupling fiber
- Optical component alignment over environmental range
- 80% duty cycle, adjustable to full power at 100%
- Spectral width FWHM < 3nm
- Center wavelength tolerance +/- 1.5 nm
- Minimum Electrical Ohmic Power Loss
- Minimum Intra-package thermal resistance
- Minimum thermal resistance - package to heatsink interface

Deployment Requirements

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Operational

- Monolithic solid state construction for high vibration immunity
- Optical wavelength and output power status monitoring
- Diode Output Power adjustment and Wavelength tuning
- Relatively high Diode Electrical to Optical efficiency
- Nominal Operating Point at 80% of maximum output power to provide N+x reserve power capability for partial diode degradation or failures
- Thermoelectric cooling with ram air heat exchange thermal dump
- Low EMI and high efficiency electrical power conditioners

Lifetime

- MTBF in operating environment greater than 4000 hours
- Minimum useful system life of greater than 10,000 hours
- Burn in before installation
- Specified optical power achievable for 1000 hours without an increase of electrical power by greater than 10%

Maintenance:

- Capable of field maintenance, repair and replacement by technicians
- Optically testable on ground and with Built in Test (BIT)

Environmental Requirements

Less than 5% reduction of optical output power subject to:

- Storage : -40^{0}C, 75^{0}C (1000 hours)
- Temperature cycling: -65^{0}C to +75^{0}C (1000 cycles, 10deg/minute ramp, 30 minute soak)
- Humidity: 85%RH/85^{0}C, 1000 hours
- Vibration: no natural modes less than 250hz
- Vibration testing: 8g rms, random
- Shock: 25g, all axes

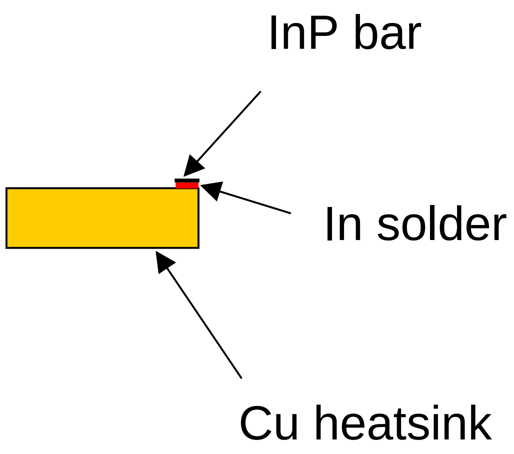
Concerns with Available High Power, Bar Packages

- **Packaging not designed reliably for harsh environments, with issues regarding:**
  - Hermeticity
  - Materials
  - Interfaces

- **High power bars typically require micro-channel cooling:**
  - Large space requirements for cooling units
  - Difficult to maintain water purity

Bar Bonding Architecture

❑ conventional architecture

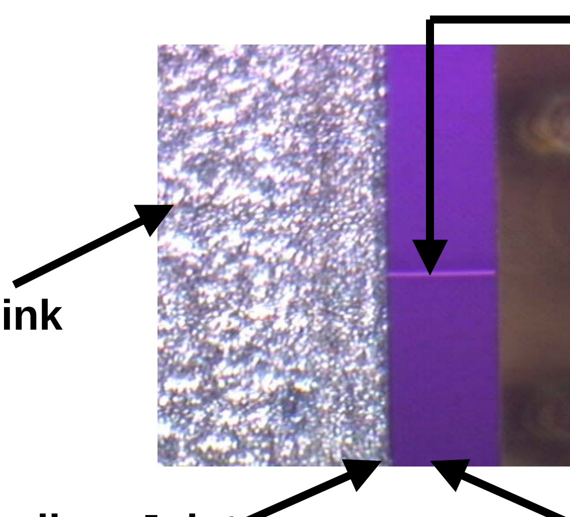


Structure	Material	Coefficient of Thermal Expansion	Thermal Conductivity
		ppm/K	W/mK
laser bar	InP	4.6	68
solder	In	29.0	86
heatsink	Cu	17.3	393

Pros	Cons
High thermal conductivity of Cu results in excellent thermal management	Known long term reliability issues with use of In – NASA and other work
In is a soft solder, absorbs CTE mismatch	Cu and InP are severely CTE mismatched. Concern about opto-mechanical stability

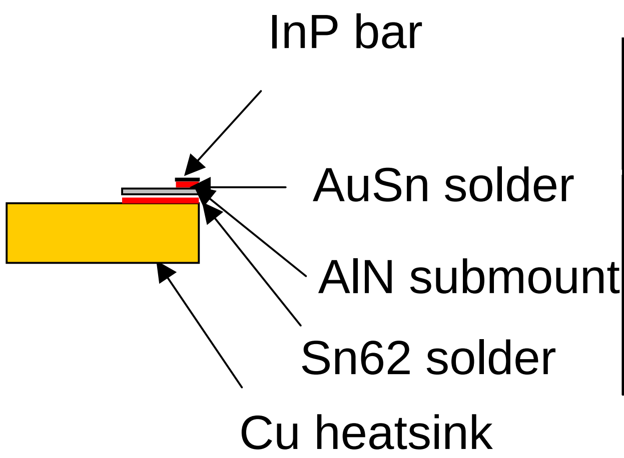
Bar Bonding Architecture - Conventional

- Linear stress modeling indicates very high stresses in Indium and InP
- Survives 60 cycles, – 40C to +75C cycling
- Subsequent cycling, 40 cycles, -65C to +75C cycling:1/3 bars shows bar cracking between 2 emitting facets, along the cavity direction



Bar Bonding Architecture

- alternate architecture



Structure	Material	Coefficient of Thermal Expansion	Thermal Conductivity
		ppm/K	W/mK
laser bar	InP	4.6	68
solder 1	AuSn	16.0	57
submount	AlN	4.5	180
solder 2	Sn62Pb36Ag2	27.0	50
heatsink	Cu	17.3	393

Pros	Cons
AuSn is a hard solder, with proven long term reliability performance	AuSn is a hard solder, no compliance – can cause high elastic stresses
AlN and InP are CTE matched, lower bar stress	Cu and AlN are CTE mismatched
Sn62Pb36Ag2 MP=179°C allows following step soldering of Cu heatsink	Heat path less efficient due to AlN and additional solder joint
High thermal conductivity of Cu provides excellent thermal management	Some concern about use of Sn62 solder – stability ?

Bar Bonding Architecture - Alternate

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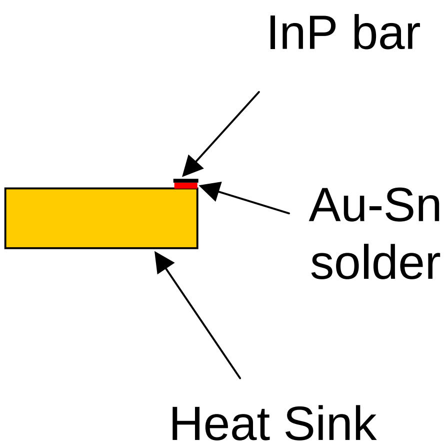
- Linear stress modeling indicates very high stresses in AlN

- Process developed for AuSn and Sn62 bonding – good smile performance, although E/O performance not ideal – indicates more development work required to assure uniform, void free, low stress joints

- 25 temperature cycles, -65C to + 75C showed cracking of AlN on 2/2 units – cracks occur along bar length direction, away from bar-AuSn-AlN joint

Bar Bonding Architecture - Options



- ❑ **Cu(10%)W:** 190 W/mK, 6.4 ppm/K
- ❑ **AlN:** 180 W/mK, 4.5 ppm/K
- ❑ **Composite Diamond:** 600 W/mK, 3 ppm/K
- ❑ **Others**

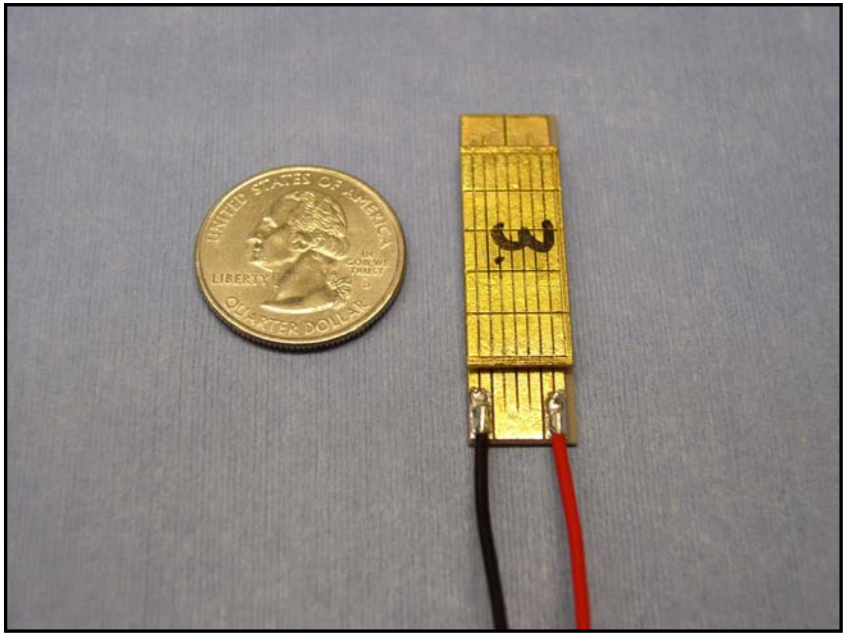
- thermally efficient
- expansion matched
- cost
- manufacturability
- compatibility with forward processes and interfaces

Cooling Challenges

- Need bars to operate at ~20-25C for optimal E/O performance and reliability
- Cooling requirements are severe – 100 W, 400W/cm2 at bar, 150W/cm2 with Cu block
- Solid state TECs have not been available to handle this type of load, hence water cooling (micro-channel coolers)
- Work emerging on more powerful TECs

Cooling Challenges

- World's highest watt density TEC.
- Maximum heat pumping: 200 watts
- This TEC's Watt Density: 58 W/cm^2
- Maximum Watt Density of current TECs: 13 W/cm^2



Courtesy: marlow industries, inc.

Cooling Challenges

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Nx1 Estimated Performance Load Lines
- Example at Delta T = 20C

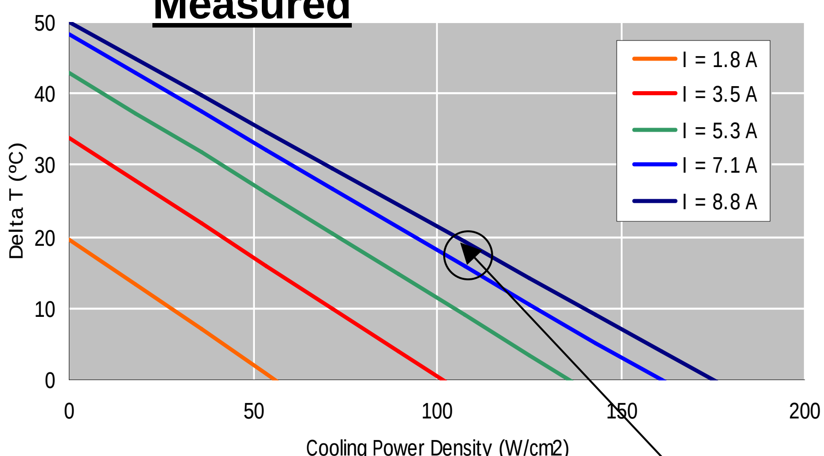
Nx1 Alpha @ Th = 85C

- Q_{load} = 4.5 W
- Q' = 110 W/cm2
- I = 8.8A

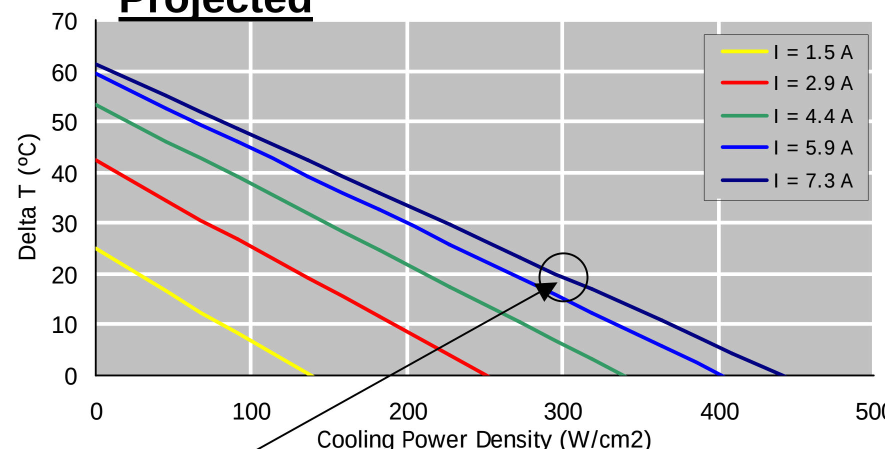
Nx1 Beta @ Th = 85C

- Q_{load} = 18.8 W
- Q' = 300 W/cm2
- I = 7.3A

Measured



Projected

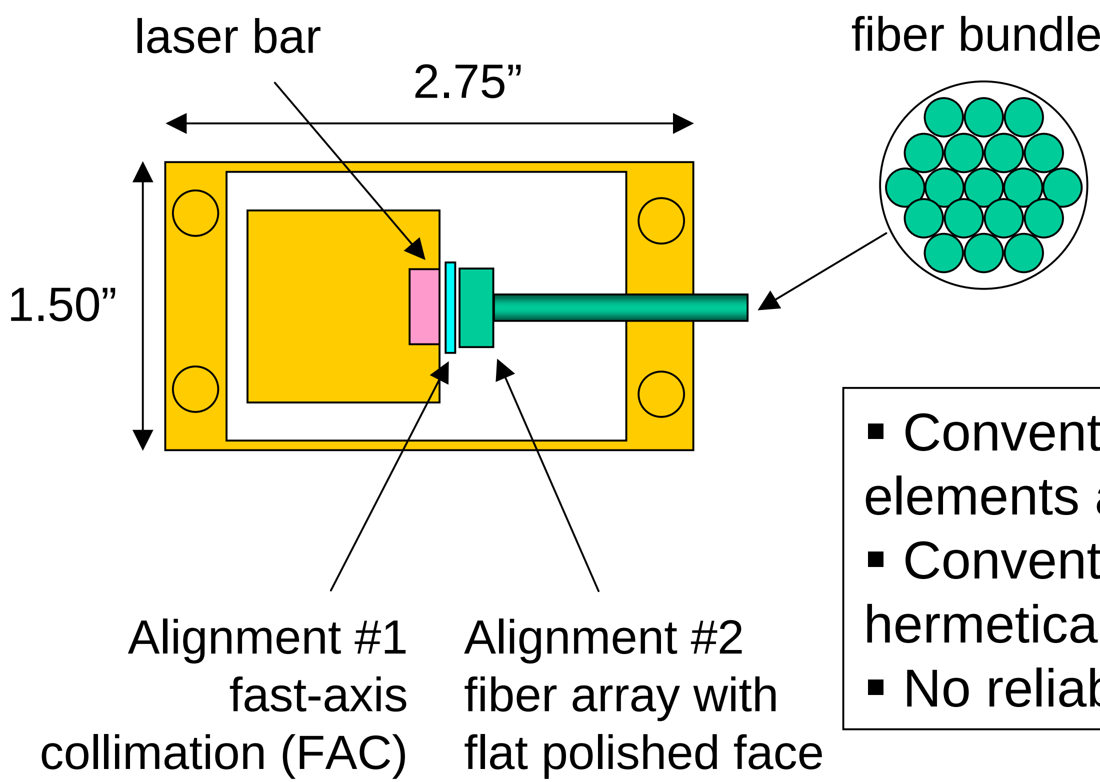


Operating point for DT=20C, maximum Heat Pumping.

Courtesy: Nextreme Thermal Solutions

Fibre Coupling Architecture

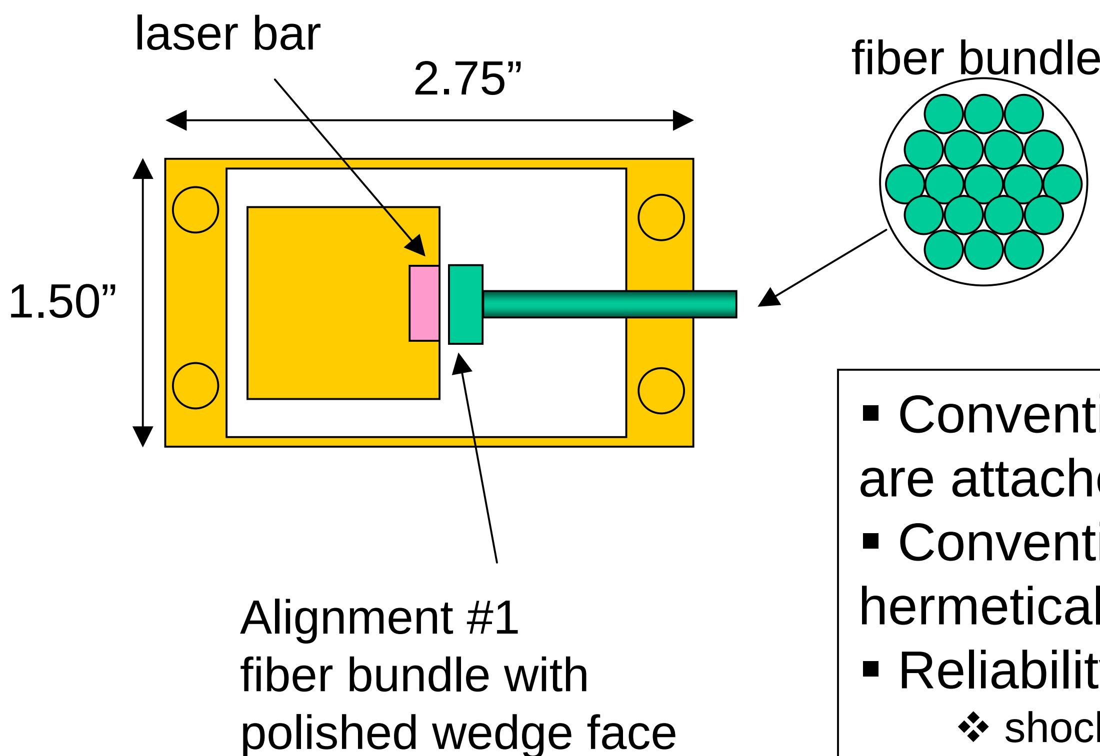
❑ **Using Fiber Array Bundle (2 alignment steps)**



- Conventionally, all optical elements are attached with epoxy.
- Conventionally the package is hermetically sealed
- No reliability data available

Fiber Coupling Architecture

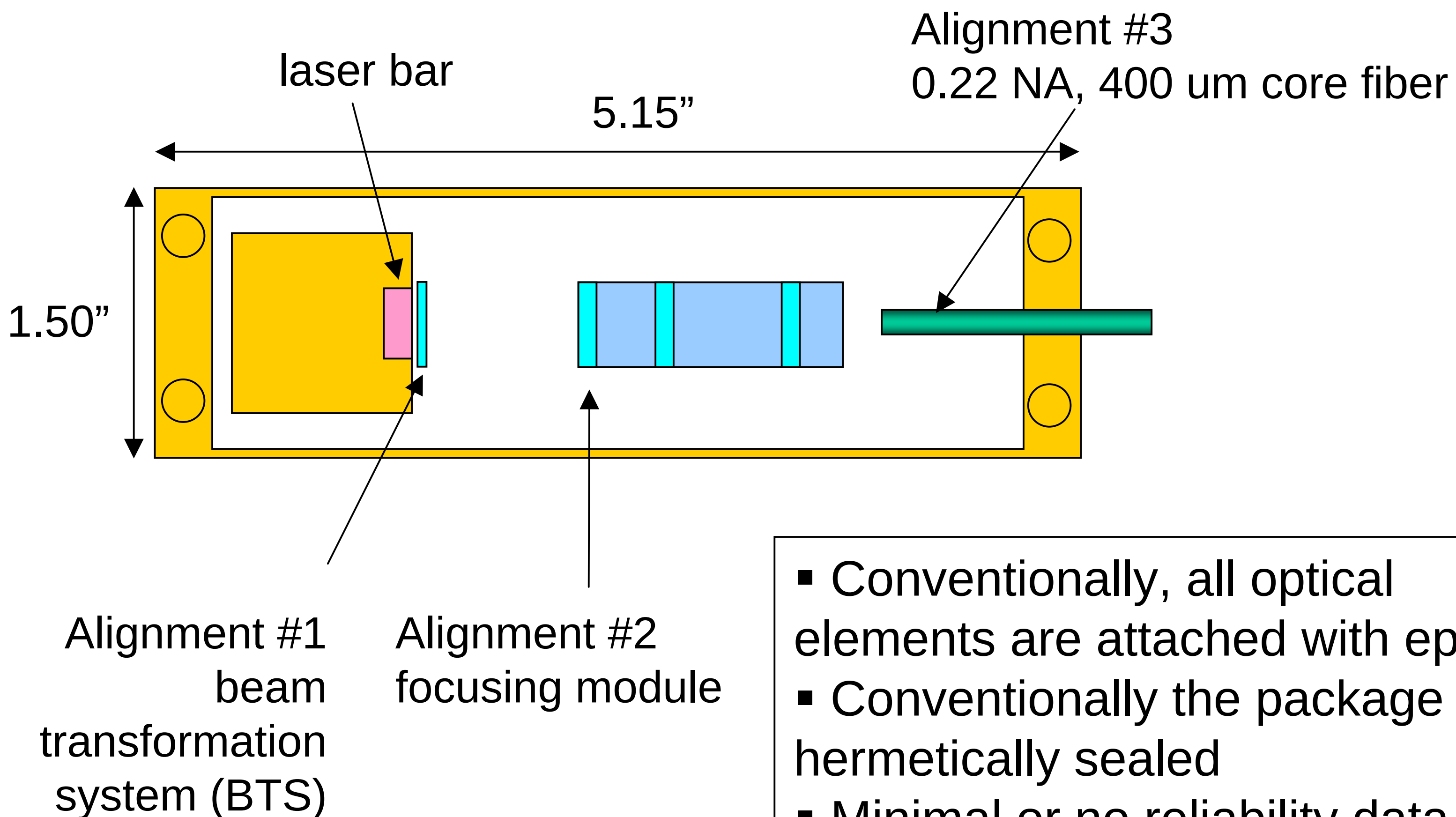
❑ Using Fiber Array Bundle (1 alignment step)



- Conventionally, all optical elements are attached with epoxy
- Conventionally the package is hermetically sealed
- Reliability reports for 808 nm bars:
  - ❖ shock & vibration passes
  - ❖ -20C to +60C TC, 50 cycles, fails 1/14
  - ❖ 10,000 hr aging @25C looks good
  - ❖ -65C to 75C TC of 1 unit shows hermeticity failure. Lid-package material are TCE mismatched. Unit performance stable

Fiber Coupling Architecture

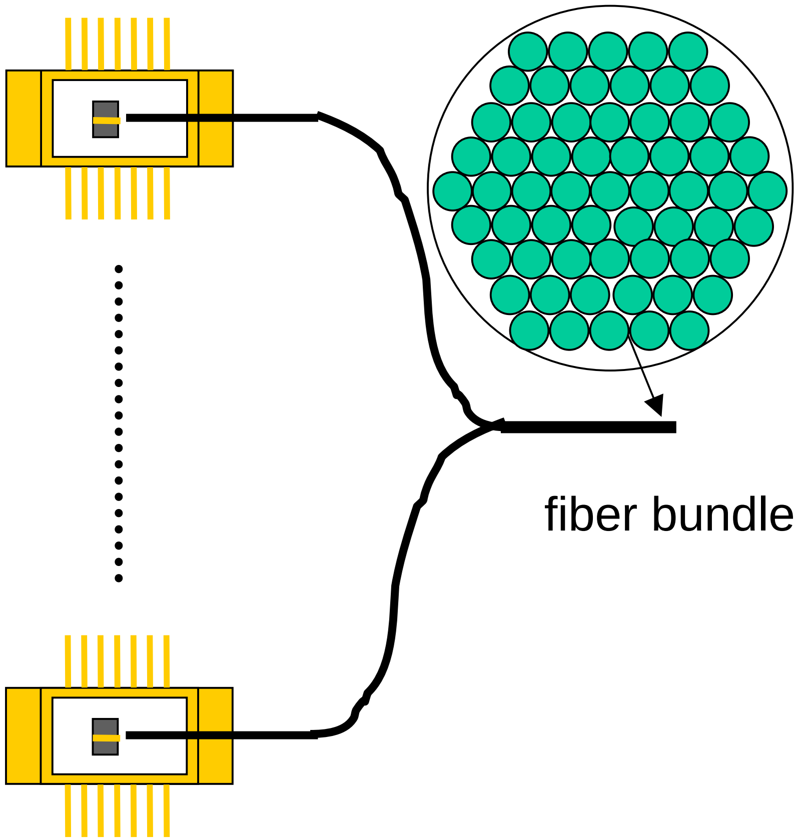
❑ **Using Hybrid-Optical-Chip (3 alignment steps)**



- Conventionally, all optical elements are attached with epoxy.
- Conventionally the package is hermetically sealed
- Minimal or no reliability data available

Individual Element Architecture

❑ **Combining Single-Emitter Packages that leverage existing Telecordia and harsh environment packaging technologies**



fiber bundle

Advantages:

- Low development risks, reliable platforms exist – lower development $ and time
- Integrated TEC, back-monitor solutions exist
- No organics/flux within hermetic enclosure
- Modular, system performance degrades more gracefully with unit failure
- Burn-in and yield issues more manageable

Disadvantages:

- Worse beam quality than bar-single fiber solution
- Higher level of fiber management
- Less compact for system deployment
- More complex TEC & wavelength control
- More expensive/W in production (?)

Summary

- Current high power laser pumps do not meet the reliability needs and requirements for operation in harsh environments
- Packaging at bar mounting level needs to consider issues related to long term reliability and TCE matching of materials – use of Cu as a sub-mount material is thermally efficient, but not reliable. Option is to use AuSn bonding of InP bars to other materials – for example, CuW, diamond, AlN
- Work on solid state TEC for integrated cooling shows promise for design into future packages
- Current options for optics alignment and fixing uses organics – more reliability and materials testing is required to understand whether these approaches are adequate, or whether epoxy free techniques from single mode laser packaging technology need to be adapted for high power laser bar packaging
- Given the maturity and large pool of reliability data that exists for Telecordia qualified, single mode lasers, an option worth considering is the use of an ensemble of single element laser modules to address pumping applications